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Microfacies Analysis and Reservoir Properties of Baba and Bajawan Formations in Selected Wells of Bai Hassan Oil Field, North Iraq

A thesis submitted to the Council of the College of Science- University of Diyala in partial fulfillment of the requirements for the degree of master in Geology \ Earth science.

BY

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Abstract

This study was conducted on the Baba and Bajawan formations, which date back to the Oligocene epoch, located in the northwestern part of Kirkuk Governorate, northern Iraq. The objective of this study is to analyze the microfacies, depositional environments, diagenetic processes, and petrophysical properties of the Bajawan and Baba formations in three wells (BH-80, BH-193, BH-194) within the Bai Hassan Oil Field..

The study relied on thin section analysis, where 105 rock samples were obtained from the three wells, provided by the North Oil Company. Petrographic analysis was carried out using a microscope and LAS file to evaluate the petrophysical properties through a specialized program (IP).

The results revealed that the studied formations contain abundant benthic foraminifera such as *Nummulites*, *Lepidocyclina*, and Miliolids, in addition to minor amounts of echinoderms, corals, and rock fragments, all embedded within a micrite and microspar matrix.

Five main types of microfacies were identified: homogeneous non-fossiliferous lime mudstone, wackestone, packstone, grainstone, and boundstone. These facies reflect variations in depositional settings.

The results showed that the Bajawan Formation was deposited in a shallow marine back-reef environment, while the Baba Formation was deposited in deeper, lower-energy settings such as shallow lagoons, reefs, and fore-reefs, reflecting a clear difference in depositional conditions between the two formations.Several diagenetic processes affecting reservoir quality were observed, including cementation, dissolution, compaction, dolomitization, and micritic calcification, which contributed to altering the petrophysical properties of the studied rocks.

The study showed that Well BH-193 has the lowest clay content, indicating a cleaner depositional environment, while Well BH-80 has the highest clay content, which may negatively impact the reservoir quality of the Bajawan Formation.

The transitional zone between Bajawan and Baba formations was relatively balanced, while the Baba Formation showed higher clay content, particularly in BH-194.

Porosity logs, such as neutron, density, and sonic logs, played a significant role in evaluating effective porosity, total porosity, and secondary porosity function. The data indicated that the Baba Formation has the highest porosity compared to the Bajawan Formation and the transitional zone, reflecting better reservoir capacity.

Well BH-194 recorded the highest porosity values overall, while BH-193 showed the lowest, indicating relatively poor reservoir quality in this well. Moreover, the results showed that both the Bajawan and Baba formations generally have low secondary porosity, suggesting limited effects of dissolution or fracturing, except for the Baba Formation in Well BH-194, which exhibited higher values, indicating a more developed secondary porosity compared to the other formations.The analysis also revealed lower effective porosity in the Bajawan Formation (ranging from 0.033 to 0.08) compared to the Baba Formation (ranging from 0.10 to 0.16), indicating that Baba has better reservoir quality and productivity. Water saturation, hydrocarbon displacement, and retention volumes were evaluated using electrical resistivity logs (LLD, ILD, MSFL).

The values showed that water saturation in the Baba Formation is low (0.048–0.94), indicating greater hydrocarbon retention, while the Bajawan Formation showed higher water saturation (0.155-0.804)potentially reducing production efficiency.

CHAPTER ONE

Introduction

1-1 Preface

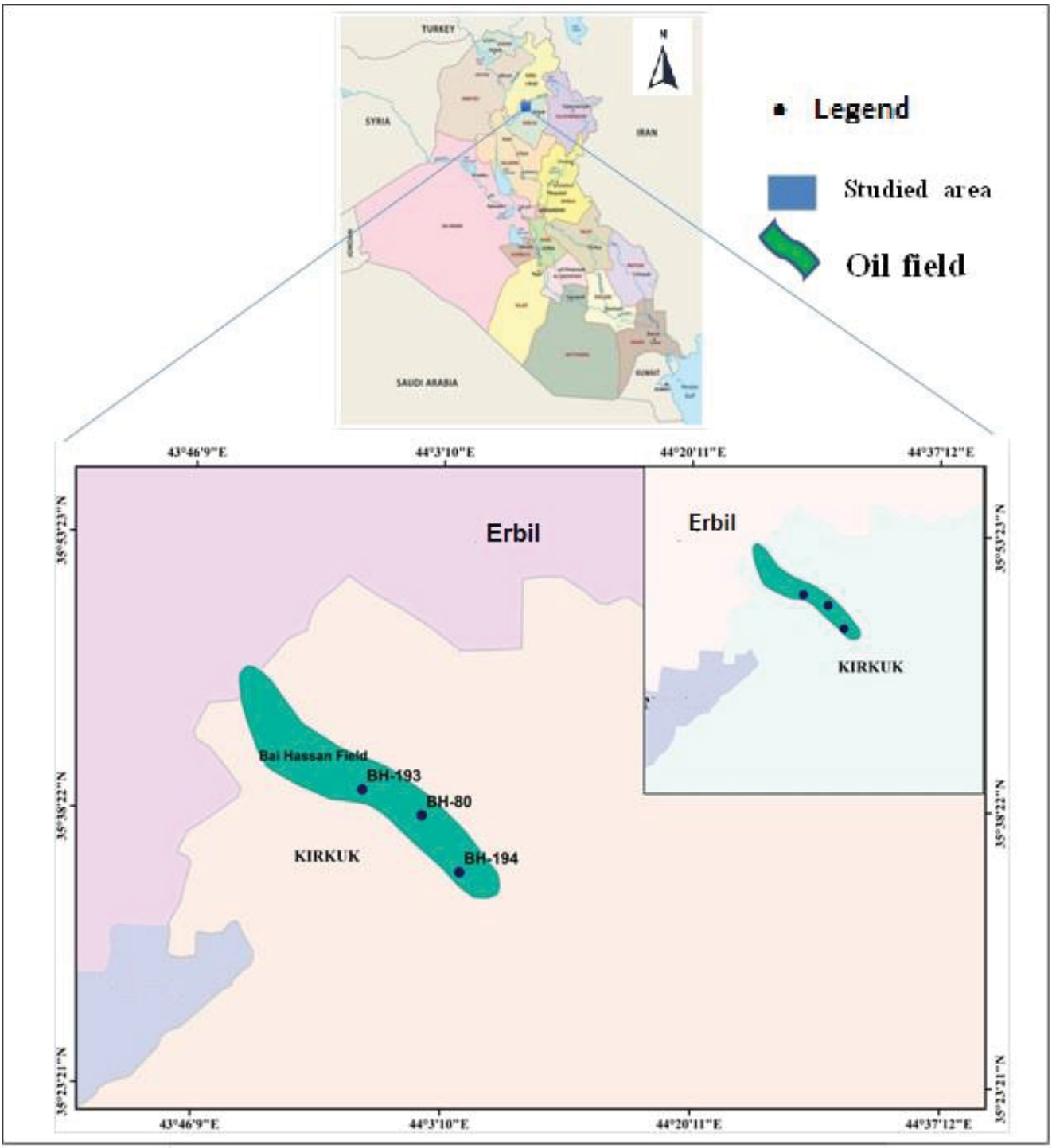
The Bai Hassan oil field is one of the most important oil fields in Iraq, located in Kirkuk Governorate in the north of the country. Discovered in the 1930s, it is part of the Kirkuk field complex. The field features geological formations rich in hydrocarbons, primarily the Baba and Bajawan formations within the Kirkuk Group (Oligocene), which contain significant oil reserves.These formations play a crucial role in oil generation and accumulation, making Bai Hassan a highly productive field with a key contribution to Iraq's economy. Ongoing geological research aims to further understand its characteristics and explore opportunities for increasing production.

1-2 Location of study area

Bai Hassan Oil Field is located in the northwest of the city of Kirkuk in northernwest Iraq, Figure (1-1). Three wells were selected from this oil field, these are: BH-80, BH-193, and BH-194. The thickness of Bajawan and Baba formations in Bai Hassan Oil Field are listed in Table (1-1).

Table (1-1): The coordinate thickness of Bajawan and Baba formations in Kirkuk Oil Field

Well no.	Coordinates		Formation	Thickness (m)	Number of slides
	Long.	Lat.			
BH-80	44° 02' 40"	35° 38' 10"	Bajawan	7	60
			Bajawan/Baba	19	
			Baba	76	
BH-193	43° 57' 20 "	35° 40' 15"	Bajawan	22.5	23
			Bajawan/Baba	18.5	
			Baba	78.5	
BH-194	44° 04' 05"	35° 34' 39"	Bajawan	17	22
			Bajawan/Baba	18	
			Baba	26	



Figure(1-1). location map of the studied oil wells.

1-3 Aims of the study

1- Determaine the Depositional environment of Baba and Bajawan formations depending on microfacies analysis.
2- Discriminate the diagenetic processes that effected the formations.
3- Determine the petrophysical properties of the formations through studing the available logs.

1-4 Geological setting:

1-4-1 Paleogeographic setting

During the Oligocene, depositional events occurred at different times, shaping the overall paleogeographic framework, which closely resembled that of the Middle to Late Eocene. Two elevated carbonate sedimentary ridges (Back Reef and Fore Reef deposits) extended in a NW-SE direction, enclosing a deep basin filled with Globigerinal Marl deposits. Previous studies, including (Dunnington,1958), indicated that this deep basin was relatively narrower during the Eocene and that the carbonate deposits of these two ridges (Back Reef and Fore Reef deposits) had limited lateral extension. This suggests that the sedimentary facies of the basin consisted of a sequence extending from the northeastern boundary of the basin represented by Back Reef, Reef, and Fore Reef deposits before transitioning into the deep basin facies (basin center). This sequence reappeared toward the southwestern margin of the basin. The Oligocene carbonate successions were described in detail for the first time in Iraq by (Bellen *et al.* 1959), identifying three superimposed reefal cycles. Each cycle includes facies deposited in Back Reef, Reef, and Fore Reef environments, with offshore sedimentary deposits forming the intermediate zones between the ridges.

• Lower Oligocene cycle: Includes the Shurau Limestone Formation (Back Reef environment), Sheikh Alas Formation (Fore Reef environment) in the northeastern part of the Oligocene basin, and the Balani Formation, representing the open sea deposits between the two ridges. The same depositional sequence is repeated in the southwestern margin of the basin.

• Middle Oligocene cycle: Includes the Baj**a**wan Limestone Formation (Back Reef environment), Baba Formation (Fore Reef environment), and the Tarjil Formation, which represents the deep basin environment.

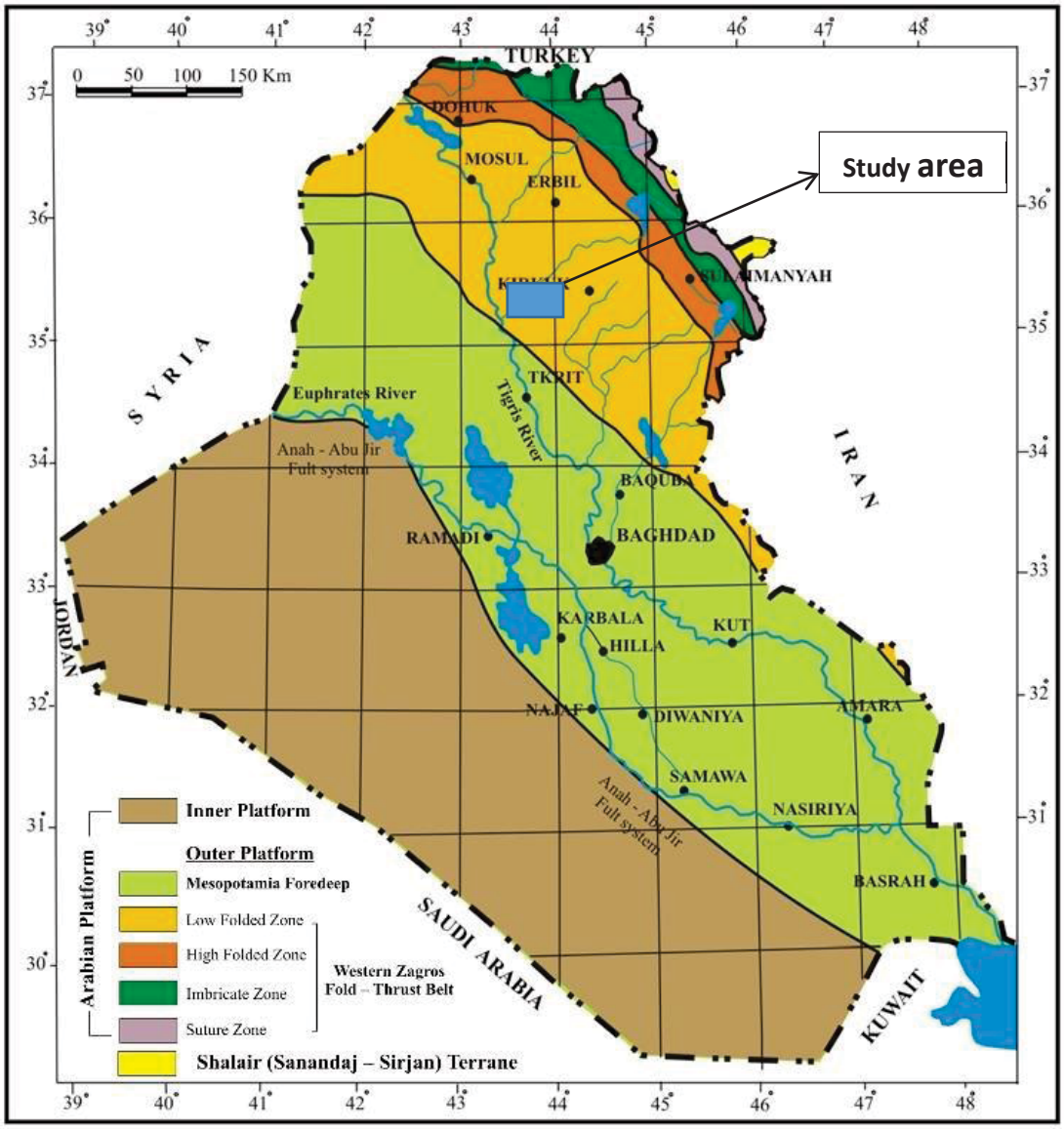
• Upper Oligocene cycle: Includes the Ana Limestone Formation (Back Reef environment), Azkand Formation (Fore Reef environment), and the Ibrahim Formation, representing deep basin deposits. The ages of these three stratigraphic cycles were determined based on their relative stratigraphic positioning within associated formations**.**

1-4-2 Tectonic setting:

According to Fouad (2015), Bai Hassan oil field underwent significant tectonic transformations during the Oligocene period. These changes coincided with tectonic activity resulting from the collision of the Arabian and Eurasian plates, creating environmental conditions that contributed to the formation of important geological structures in the region.

The field is located within the Low Folded Zone in northeastern Iraq, which is part of the Unstable Arabian Shelf and lies near the Zagros Fold Belt along Iraq's eastern border(Figure 1-2). The geological structures in this zone are typically elongated and asymmetrical anticlines, playing a crucial role in oil accumulation. Additionally, the sequential topographic and geological configuration of the Bai Hassan oil field is essential for the preservation and accumulation of hydrocarbons.

These tectonic shifts created favorable conditions for hydrocarbon deposits, while climatic changes during this period directly influenced sedimentation and depositional environments, fostering the development of diverse sedimentary settings (Fouad, 2015).



Figure(1-2) Tectonic map of Iraq (Fouad, 2015).

1-4-3 Stratigraphic setting

The study of the nature of contact surfaces and lithological characteristics is crucial for determining the stratigraphy of any formation. Contact surfaces vary depending on the identity of the overlying and underlying formations.

Buday (1980) indicated that the upper contact surface between the Baba Formation and the overlying Bajawan Formation is conformable. However, the contact surface between the Bajawan Formation and the overlying Jeribe Formation is considered an unconformable surface, indicating a period of deposition interruption or erosion before the Jeribe Formation was deposited above the Bajawan Formation.

Al-Naqib (1960) stated that the upper contact surface of the Baba Formation is conformable with the Bajawan Formation in the southern region of the Kirkuk field. Kharajiany (2008) suggested that the Tarjil Formation, which lies beneath the Baba Formation, likely has a conformable contact surface between them. The representative section of the Bajawan Formation in the well BH-194.

The formation consists of white-creamy, medium hard-hard, crystalline, dense, pyritic, marly, and light brown, medium hard, porous, crystalline limestone. The lower part of the Bajawan Formation, which interlaces with the Baba Formation, consists of limestone, creamy light gray, medium hard, fine crystalline, marly, and, light brown, medium hard, crystalline, dolomitic, vuggy, porous limestone (Final well report). Whereas the Baba Formation consists of dolomitic limestone, light brown, medium hard, fine crystalline, vuggy, porous. The Baba Formation is bounded from below by the Tarjil Formation, which has a thickness of 12 meters and consists of limestone, brown, medium hard, Crystalline, porous, marly (final well report).

1-5 Previous Studies

- Bellen *et al.* (1959) indicated that the age of the Baba Formation dates back to the Middle Oligocene, while later studies suggested that the upper part of the formation in the Anah area may extend to the Late Oligocene. These studies were based on previous research, as Bellen (1956) first described the Baba Formation through the study of Kirkuk Oil Well 109-K, explaining that the formation consists of dolomitized, porous limestone, which appears chalky in outcrops, is mostly massive, and occasionally bedded in some parts. He also noted that the formation was deposited in a fore-reef environment along the northeastern and southwestern margins of the Oligocene Basin. Bellen's study was based on the work of Henson (1950), who described the reefal limestone rocks in Kirkuk and introduced the term "Reef Complex" for a group of limestone rocks associated with coral reefs. He identified reef zones including the back reef, reef, and fore-reef, emphasizing that these deposits play a crucial role in oil generation, migration, accumulation, and storage due to their primary and secondary porosity. Based on these studies, three distinct depositional cycles of reef formations were identified, including the lower formations (Shuaro, Sheikh Alas, and Balani), the middle formations (Bajawan, Baba, and Tarjil), and the upper formations (Anah, Azkand, and Ibrahim).
- Youkhanna and Hradecky(1978) recorded the presence of certain Oligocene formations, including the Shurau, Bajawan, Baba, Azkand, and Anah formations, within the Bamu Anticline near the Darbandikhan area, with a thickness of approximately 82 meters.
- Muhammad (1983) studied the biostratigraphy of the Kirkuk Group formations in the Kirkuk and Bai Hassan areas. He indicated that the deposits of the Kirkuk Group were formed in back reef, fore reef, and deep basin

environments, and noted that the Baba Formation is deposited in the fore reef area.

- Majid and Veizer (1986) identified the age of the Kirkuk Group as early and middle Oligocene. The early Oligocene layers include the Shuwairo Formation, representing the back reef environment, and the Sheikh Alas and Balani Formations, representing the fore reef environment. In contrast, the middle Oligocene layers include the Bajawan Formation (back reef), the Baba Formation (reef), and the Tarjil Formation (fore reef).
- El-Eissa (1992) studied the formations of the Kirkuk Group in the Kirkuk oil field and divided them into early Oligocene, which includes the Palani, Sheikh Alas, and Shuwairo formations, and late Oligocene, which includes the Tarjil, Baba, and Bajawan formations.
- Jassim and Goff (2006) reorganized the Oligocene deposits based on the stratigraphic sequence into two main sequences: the lower and upper sequences. The lower sequence includes the Sheikh Alas and Shuwairo formations with the base consisting of the Balani and Tarjil formations, while the upper sequence includes the Bajawan, Baba, Anah, and Azkand formations, and the base consisting of the Ibrahim formation.
- Al-Tamimi (2011) studied the stratigraphy and reservoir characteristics of the Oligocene successions in the Kirkuk area. He identified four ancient environments and classified the Baba Formation environment as a coral reef and open marine setting.
- Ghafor (2011) analyzed the microfacies and biostratigraphy of the Baba Formation in the Kirkuk area, revealing that the fossil assemblages present in the formation indicate a Late Oligocene age.
- Ghafur (2015) conducted a study on an integrated depositional model for the Kirkuk Limestone Group in southern Sulaymaniyah, Kurdistan, northern

Iraq. The main objective of this research was to document the various microenvironments, their relationships, and environmental interpretations to produce an integrated depositional model for the Kirkuk Group, including the Baba Formation, to compare it with regional and global data.

- Al-Jwaini (2015) studied the hydrocarbon reservoir units in the Kirkuk oil field wells and found that they consist of four reservoir units that cover the Oligocene formations, including the Baba Formation. The study identified different types of porosity, such as porosity within grains, porosity between blocks, fracture and channel porosity, mold porosity, caverns, and voids. The formation of these porosities was attributed to processes of dissolution and dolomitization.
- Farhan *et al.* (2016) conducted a petrographic study of the Baba Formation rocks found in selected wells within the Kirkuk oil field. They identified two main facies, and based on these detailed facies, they determined the depositional environments, which were represented by the fore-reef environment.
- Ghafor and Najaflo (2022) studied the biostratigraphy, microfacies, ancient environment, and climate of the Baba Formation in Kirkuk, northeastern Iraq, in the Bai Hassan field. They determined the age of the formation to be from the Late Rupelian to Early Chattian, based on types of foraminifera. They also indicated that the depositional environment of the Baba Formation is a carbonate ramp.
- Al-Bayati (2023) conducted a sedimentary and sequence stratigraphic study of the Oligocene successions in central Iraq, analyzing eight surface and subsurface sections. He indicated that the rocks of the Baba Formation successions consist of limestone and dolomite, identifying two types of benthic foraminiferal shells: *Lepidocyclina* and *Nummulites.* He

distinguished four microfacies that reflect the deposition of the formation in a lagoon-reef environment.

- Hassan (2023) carried out a sedimentary and organic geochemical study of the Oligocene successions in selected wells from the Bai Hassan oil field in northern Iraq. He indicated that the rocks of the Baba Formation were deposited on the elevated parts of the outer middle ramp within the carbonate platform.